

BRUGG CABLE MESH ROCKFALL FENCE

FINAL REPORT

Experimental Features
Project No. OR 90-03

Shellrock Mountain
Columbia River Highway (Interstate 84)
Hood River County
Federal Aid # IR-84-2(31)052

by

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<p>16. Abstract</p> <p>In 1991 a Brugg Cable Mesh Rockfall Fence was installed along Interstate 84 (I-84) 52 miles (84 km) east of Portland to prevent large boulders, that roll down the 1500-foot (460 m) long talus slope of Shellrock Mountain, from entering the travel lanes. This was one of the first major installations of this fence on an Interstate Highway and was an FHWA experimental features project.</p> <p>The Brugg Cable Mesh Rockfall Fence was selected for this site because it was the most cost effective and visually acceptable option that could be built on top of the existing bin wall. Also, because it could efficiently stop the large boulders that entered the travel lanes approximately every three years with the incorporation of a friction brake energy dissipator. During design, the standard tie-back anchors were eliminated to prevent damaging the talus slope and the Historic Columbia River Highway.</p> <p>This was the first installation of the fence both for ODOT and the contractor. Both considered construction very simple except for difficulties spray painting the fence on site due to the high winds. It was found that during design it is critical to have an accurate ground profile along the fence line to prevent changes during construction.</p> <p>On August 8, 1992 a 1.7-ton (1.5-metric ton) boulder impacted a 6.5-foot (2.0 m) high mesh section three feet (0.9 m) from a post. The fence stopped the boulder, however, the post and foundation rotated 20 degrees due to the foundations inability to resist the impact moment without the tie-backs. The velocity of the rock at impact was estimated to be 33 feet/second (10 m/sec) and the kinetic energy was approximately 66,000 foot-pounds (89 000 joules). The damage to the fence from this event was minor and has been repaired.</p> <p>In the winter of 1993-1994, a 750-pound (340 kg) boulder impacted the second from the last mesh section, one foot (0.3 m) from the top. It resulted in only superficial damage not requiring repair.</p>			
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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
<u>LENGTH</u>				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
<u>AREA</u>				
in ²	square inches	645.2	millimeters squared	mm ²
ft ²	square feet	0.093	meters squared	m ²
yd ²	square yards	0.836	meters squared	m ²
ac	acres	0.405	hectares	ha
mi ²	square miles	2.59	kilometers squared	km ²
<u>VOLUME</u>				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft ³	cubic feet	0.028	meters cubed	m ³
yd ³	cubic yards	0.765	meters cubed	m ³
NOTE: Volumes greater than 1000 L shall be shown in m ³ .				
<u>MASS</u>				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
<u>TEMPERATURE (exact)</u>				
°F	Fahrenheit temperature	5(F-32)/9	Celsius temperature	°C

* SI is the symbol for the International System of Measurement

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
<u>LENGTH</u>				
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
<u>AREA</u>				
mm ²	millimeters squared	0.0016	square inches	in ²
m ²	meters squared	10.764	square feet	ft ²
ha	hectares	2.47	acres	ac
km ²	kilometers squared	0.386	square miles	mi ²
<u>VOLUME</u>				
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m ³	meters cubed	35.315	cubic feet	ft ³
m ³	meters cubed	1.308	cubic yards	yd ³
<u>MASS</u>				
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T
<u>TEMPERATURE (exact)</u>				
°C	Celsius temperature	1.8 + 32	Fahrenheit	°F



(4-7-94 jbp)

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Special acknowledgement to Tim Pfeiffer for performing the calculation of the rock energy and velocity presented in this report. Ron Chassie's review of this report was invaluable.

DISCLAIMER

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**BRUGG CABLE MESH ROCKFALL FENCE
FINAL REPORT**

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1.0 INTRODUCTION

In 1991 a Brugg Cable Mesh Rockfall Fence was installed along Interstate 84 (I-84) from MP 52.1 to 52.7 (Figure 1.1) to prevent large boulders from falling in the travel lanes. This was one of the first major installations of the Brugg Cable Mesh Rockfall Fence on a U.S. Interstate Highway and was designated a Federal Highway Administration (FHWA) experimental features project. The fence installed at Shellrock Mountain stopped a 1.7-ton (1.5-metric ton) boulder on August 8, 1992. The fence sustained minor damage, but has since been repaired. Sometime during the winter of 1993-1994 the fence also stopped a 750-pound (340 kg) boulder without significant damage.

The previously written Construction Report for this experimental features project evaluated the construction, cost, visual impact, and design of the Brugg Cable Mesh Rockfall Fence. This report summarizes those findings and evaluates the rockfall mitigation effectiveness and fence maintenance.

1.1 BACKGROUND

Shellrock Mountain is a volcanic neck of dacite intrusive rock, surrounded by a talus slope up to 1,500 feet (460 m) high. Rocks one to four feet (0.3 to 1.2 m) in diameter, fall from the cliffs above the talus and roll down its slope.

Sections of metal bin wall of varying heights were installed in 1964 between I-84 and the talus slope, forming a rock fallout area. Approximately every three years a boulder reached the I-84 travel lanes where the bin wall was of insufficient height or non-existent to stop it.

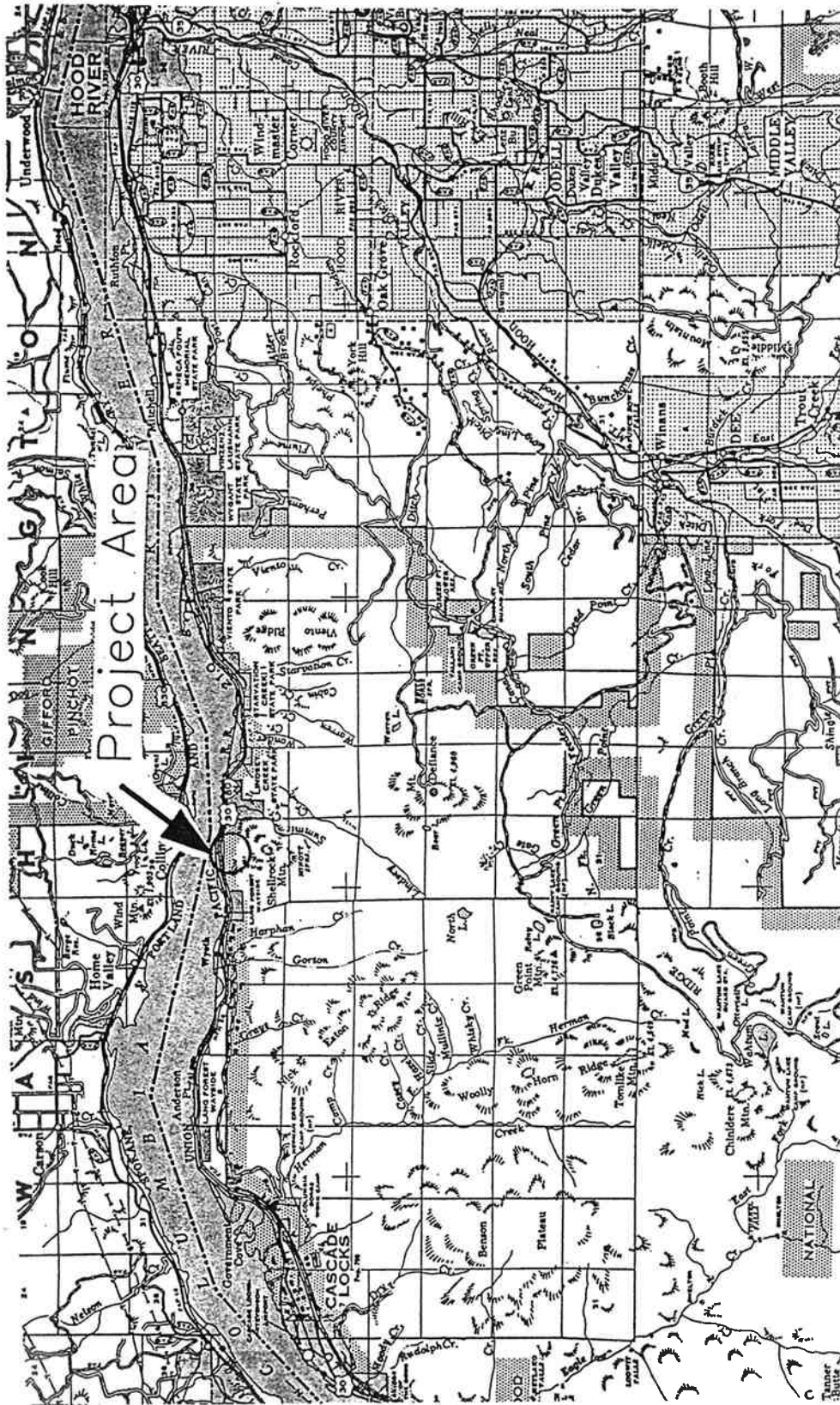
The following criteria were used in selecting a rockfall mitigation to supplement the bin wall:

1. Protection of the I-84 travel lanes from rocks up to four feet in diameter.
2. Cost and ease of maintenance and repair by maintenance crews.
3. Cost effectiveness when compared to other equally effective mitigation measures.
4. Minimization of visual impact.
5. Constructability on top of the existing bin walls.
6. Minimization of disruption to the existing talus slope environment.

7. Preservation of segments of the Historic Columbia River Highway found behind the existing bin walls.

The Brugg Cable Mesh fence was selected and installed along the top of and between sections of the existing bin wall to improve rockfall containment. The fence is a patented proprietary item and consists of cable mesh sections attached to H-beam posts that incorporate friction brakes in the attachment cables. The FHWA experimental features designation allowed the use and evaluation of a sole source proprietary item.

To summarize the construction report, the Brugg Cable Mesh Rockfall Fence was the most cost effective and visually acceptable option that could be built on the top of the bin wall. Although this was the first installation for the Contractor and ODOT, both considered construction to be very simple, except for difficulties spray painting on site due to high winds. The standard tie-back anchors were eliminated for this project to prevent disruption to the talus slope and damage to the Historic Columbia River Highway. Their elimination also made future development possible along the Historic Highway.



SCALE: 1 inch = 2.2 miles (approx.)



Figure 1.1 Project location.

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2.0 ROCKFALL MITIGATION EFFECTIVENESS

2.1 AUGUST 8, 1992 ROCKFALL

On August 8, 1992, a 1.7-ton (1.5-metric ton) boulder hit the fence (Figure 2.1). The boulder dislodged from the cliffs above the talus, bounced and rolled down the slope (Figure 2.2) and impacted the 6.5-foot (2.0 m) high fence at Sta. 567+80, about mid-height. The distance between the observable bounces were surveyed (Figure 2.3) and found to vary from five to fifty feet (1.5 to 15 m) along the slope. The final bounce was in the fallout area near the toe of the slope (Figure 2.4). The rock impacted the fence three feet (0.9 m) from a post, imparting much of its force to the post and its foundation, causing the foundation to rotate approximately 20 degrees. The fence, however, stopped the rock and prevented it from entering the travel lanes.

Velocity estimates and energy calculations for the rock were made by Tim Pfeiffer (ODOT Geotechnical Designer). The velocity was estimated to be 33 feet/second (10 m/sec) and the kinetic energy at impact was approximately 66,000 foot-pounds (89 000 joules).

The rock was approximately the same size as the design rockfall, but due to its trajectory the calculated energy was less than the 150,000 foot-pound (200 000 joules) design energy. Although the impact was less than the design energy, the foundation rotated. The rotation was due to the post not breaking-away as designed and the foundation's inability to resist the impact moment without the tie-backs.

The Brugg Cable Mesh Fence was damaged as it dissipated the energy of the rockfall (Figure 2.5). The damaged portions of the fence are shown in the typical drawing in Figure 2.6. The following is a list of the damage:

1. The upper friction brake was pulled 22 inches (560 mm) (Figure 2.7).
2. The lower friction brake was pulled one inch (25 mm).
3. The seam rope pulled five inches (130 mm).
4. Three 'C' type cable clamps opened.
5. The post and foundation nearest the impact rotated 20 degrees, with no damage to post attachment bolts.

6. The bolt for the lower flange (for lower perimeter cable) bent.
7. The metal bin wall cap was damaged by the post.

The fence was not permanently damaged and only minor repair was required. The contractor that initially installed the fence repaired the damage. The repair required removing the mesh section, digging out and resetting the foundation, resetting the upper friction brake and perimeter cable, and reattaching the mesh section. The cost of the repairs was \$4,400. Figure 2.8 is a photo of the repaired fence.

2.2 WINTER 1993 - 1994 ROCKFALL

Sometime during the winter of 1993 -1994 a boulder impacted the second to last mesh section fence approximately Sta. 578 + 75 (Figure 2.9). Other rocks associated with this rockfall were also in the fallout area (Figure 2.9). The boulder weighed approximately 750 pounds (340 kg) with dimensions 2.3' x 2' x 1' (0.70 m x 0.61 m x 0.30 m) (Figure 2.10). The impact was located one foot (0.3 m) from the top of the fence and 5.5 feet (1.7 m) from the eastern post (Figure 2.11). The slope distance of the last bounce from the southern edge of the fallout area was approximately 40 feet (12 m).

The fence incurred only minimal damage. It included:

1. Distortion of the cable and the gabion mesh (Figure 2.12).
2. On the impacted section, the upper friction brake slipped one inch (25 mm) (Figure 2.13).
3. On each adjacent mesh section, the upper friction brake slipped 1/2 inch (13 mm).
4. The lacing rope was stretched on the impacted section.
5. The eastern post on the impacted section rotated two degrees.

This damage was only superficial and required no repair.



**Figure 2.1 The Brugg Cable Mesh Rockfall Fence after the August 8, 1992 rockfall impact.
(The posts are 8 feet high) (2.4 m).**



Figure 2.2 Rock bounce marks on the talus slope.

ROCKFALL BOUNCE LOCATIONS

AUGUST 8, 1992

STA. 567+80

SCALE: 1 inch = 40 feet

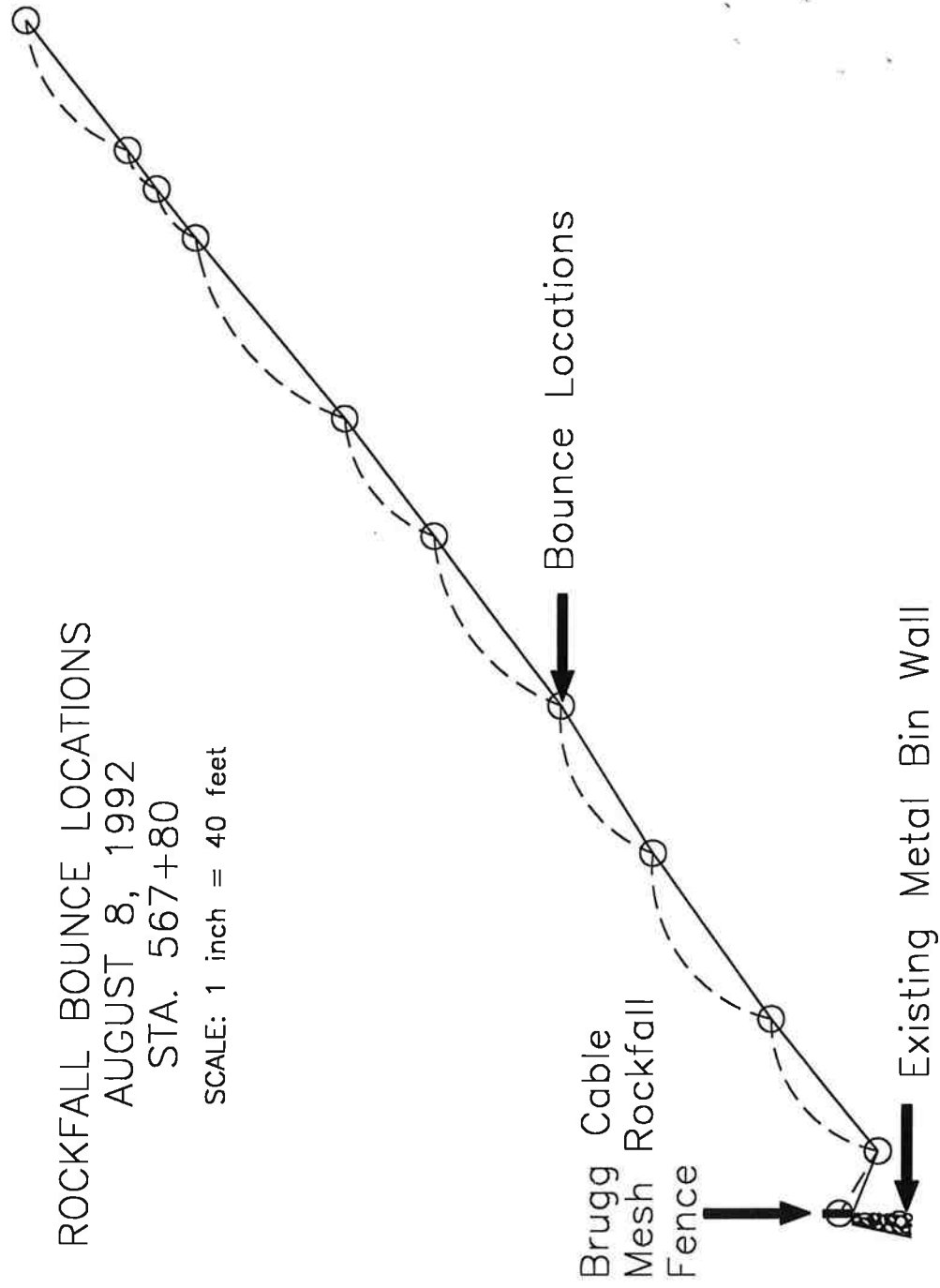


Figure 2.3 Rockfall bounce locations at STA 567+80



Figure 2.4 Final bounce in the fallout area.

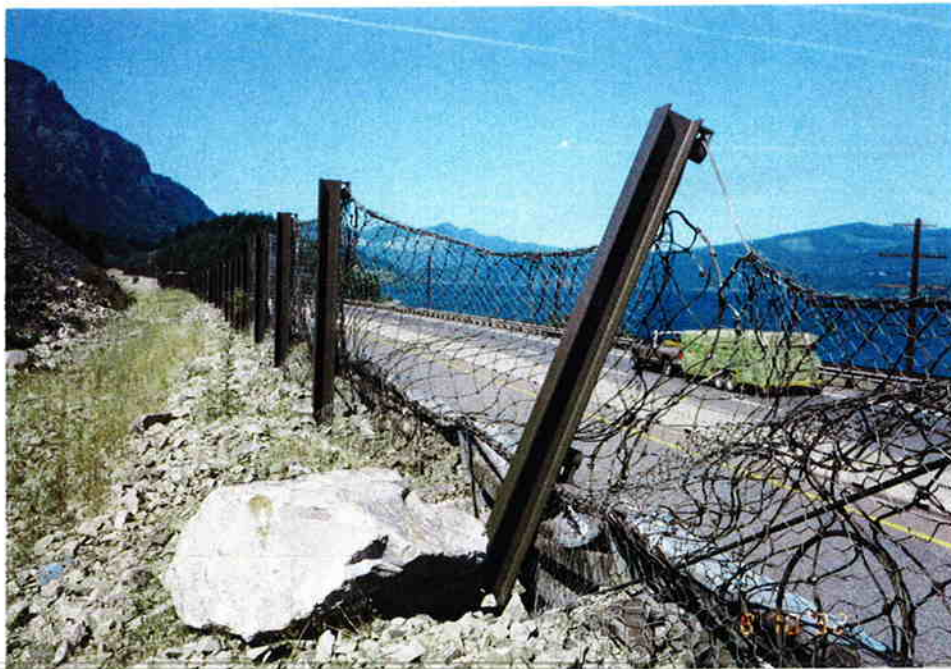
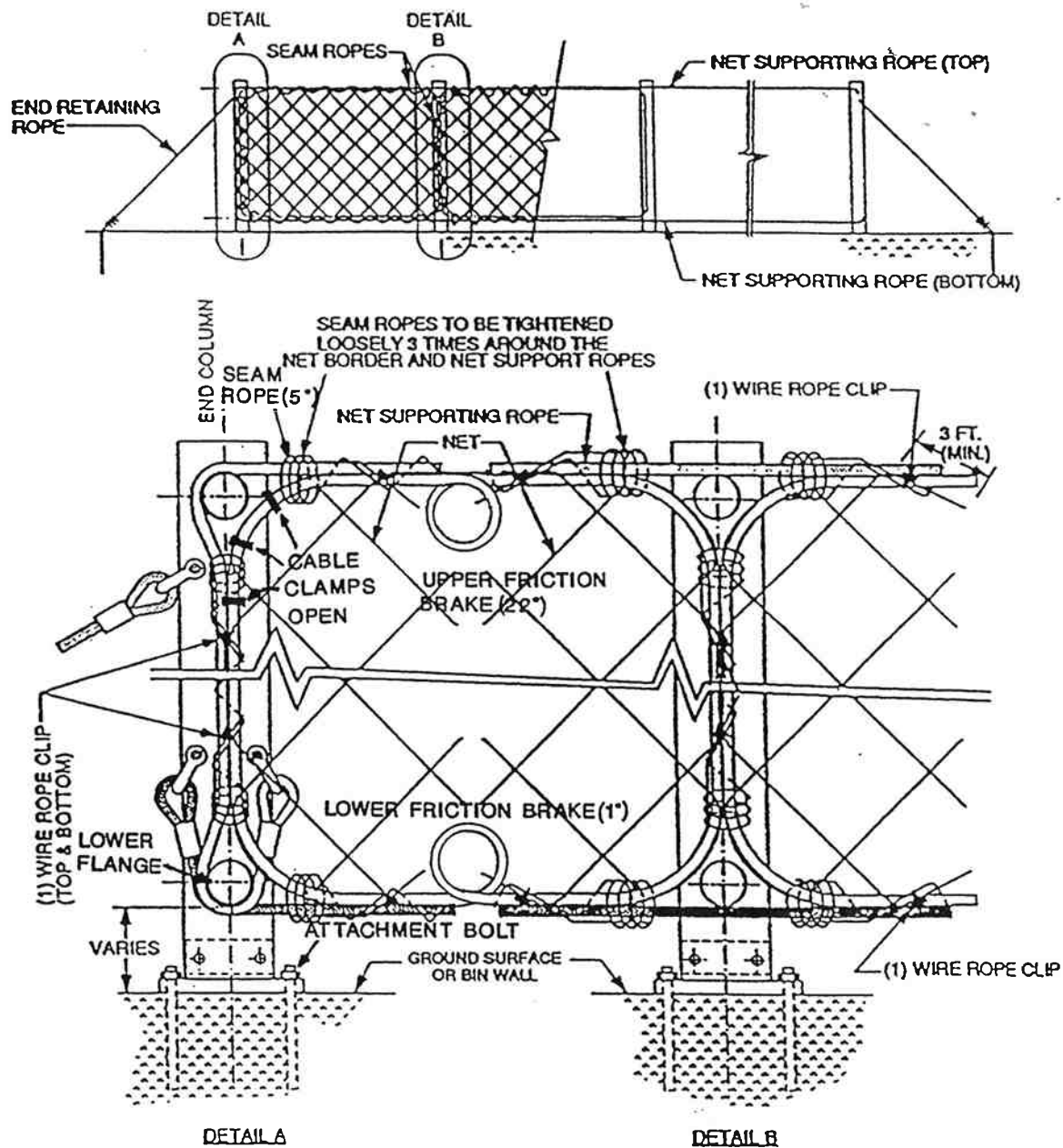


Figure 2.5 The damaged fence.



TYPICAL WIRE ROPE NET
INSTALLATION DETAIL

BCP-H-8

Figure 2.6 Typical detail with damage description.



Figure 2.7 The top friction brake pulled 22 inches (560 mm).

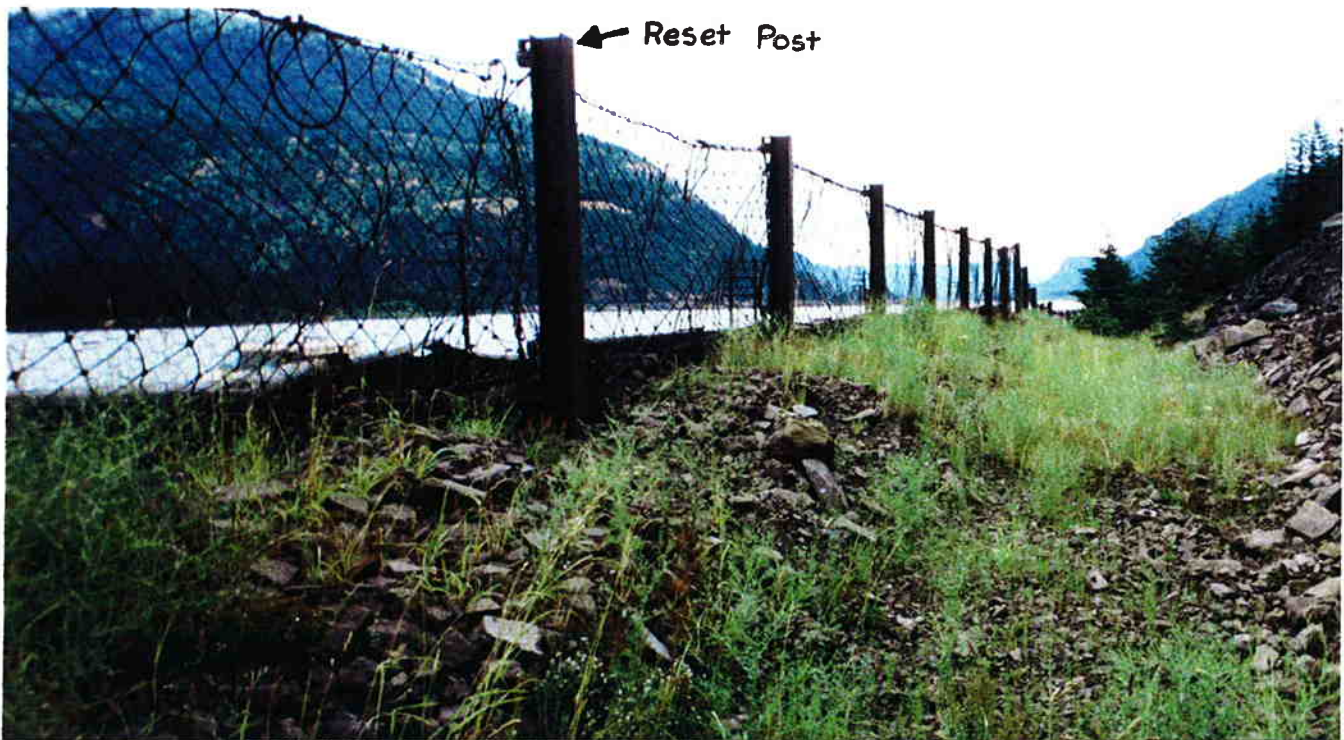


Figure 2.8 The repaired fence.

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Figure 2.9 Looking east at the impacted mesh section. The boulder in the foreground impacted the fence. The boulder in the background did not, it rolled up to this position.
Photo taken 5/13/94.



Figure 2.10 The boulder that impacted the fence.
Photo taken 5/13/94.

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Figure 2.11 Looking west at the location on the mesh section of the impact.
Photo taken 5/13/94.



Figure 2.12 Distortion of both the cable and gabion mesh
Photo taken 5/13/94.

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**Figure 2.13 The slip on the upper friction brake.
Photo taken 5/13/94.**

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3.0 CONCLUSIONS AND RECOMMENDATIONS

3.1 CONCLUSIONS

The Brugg Cable Mesh Rockfall Fence was successful in stopping a 1.7-ton (1.5-metric ton) rock with only minor damage and a 750-pound (340 kg) rock with no significant damage. The damage from the impact of the larger rock indicates:

1. The foundation without the tie-back was inadequate to resist rotation of a design rockfall when the impact is close to the post.
2. The post did not break-away as designed and it appears that the attachment bolts are over designed.

These design factors together resulted in increased maintenance and repair costs from the larger rockfall event, but they do not appear to have reduced the effectiveness of the fence. The Brugg Cable Mesh Fence met the selection criteria, was easy to construct, requires simple maintenance, and so far has been effective in preventing boulders from entering the travel lanes.

3.2 RECOMMENDATIONS

The Brugg Cable Mesh Fence should be considered when designing mitigation for high energy rock fall areas. If the Brugg fence is selected, the foundation should be carefully designed to resist rotation.